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Environmental impacts and risks of the national renewable energy targets – A review and a qualitative case study from Finland

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ABSTRACT

The EU is aiming to increase the utilisation of renewable energy to 20% of the total energy consumption by 2020. For Finland, the target is 38%. Renewable energy sources are assumed to reduce greenhouse gas emissions when compared to fossil fuels. Yet not all environmental impacts of renewable energy use are thoroughly assessed, and there are no comprehensive assessments on the impacts and risks of renewable energy production that would take into account all possible environmental impacts. We applied qualitative expert knowledge to attain information on the impacts and risks of renewable energy in Finland. According to the expert panel, the overall impacts of renewable energy by 2020 are not significant. However, we found some hot spot areas, i.e. areas of the most concern related to particulate matter formation during regional wood combustion, climate impacts of forest energy, biodiversity impacts connected to several renewable energy sources, and eutrophication caused by utilisation of agricultural energy sources. There are currently no reliable and generally accepted methods to estimate the biodiversity impacts of renewable energy production, thus, this topic would require further studies. The climate change impacts of forest based energy sources are relatively well studied, but the results of these studies are highly variable because of different assumptions on spatial and time scale. A qualitative impact assessment framework, as described in this paper, can be used to assess the environmental impacts of renewable energy production and is a potential option to attain information on the renewable energy impacts as long as reliable and comparable quantitative datasets are not available. These kinds of qualitative assessments can also be applied to detect the areas that need further studies.

1. Introduction

The EU is aiming to increase the use of renewable energy to 20% of the total energy consumption by 2020 [1]. The directive obligates the EU member states to provide National Renewable Energy Action Plans, giving a description of pathway to reaching their national-level renewable targets under the directive. To attain these targets, countries need to make modifications to their current energy mixes. The country-specific targets for the member countries vary (Table 1). For Finland, the target is set for 38%. Finland has a long tradition of using forest biomass in combined heat and power (CHP) and heat production, but in the future, the utilisation of other renewable energy sources, such as wind power, liquid biofuels and heat pumps, will increase. It has been estimated that Finland can increase, in the most optimised case, the share of renewable energy sources up to 44–50% [2]. Justifications for the utilisation of renewable energy resources are based on reduction of greenhouse gas (GHG) emissions. The EU has agreed on to reduce GHG-emissions 40% from the 1990 level by 2030 [3]. The decisions concerning the use of renewable resources must be made at present, due to the immediate need to cut down GHG-emissions. However, determining the exact values for the amount of GHG-emissions and fossil energy consumption saved by a certain bioenergy product is demanding because of methodological and conceptual variation in the assessments (see e.g. [4,5]).

The mitigation of climate change via renewable energy has been under an active political and scientific discourse. High proportion of renewable energy mixes may be feasible in many locations [6], but the environmental impact assessments of renewable energy include several sources of uncertainties (see e.g. [7,8]). Despite the fact that climate change is considered to be an important environmental impact, other

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Table 1
National targets for the share of renewable energy sources in 2020, according to Directive. 2009/28/EC.

Regions	Share of energy from renewable sources in gross final consumption of energy	
	2005	2020
Sweden	39.8	49.0
Latvia	32.6	40.0
Finland	28.5	38.0
Austria	23.3	34.0
Portugal	20.5	31.0
Estonia	18.0	25.0
Romania	17.8	24.0
Denmark	17.0	30.0
Slovenia	16.0	25.0
Lithuania	15.0	23.0
France	10.3	23.0
Bulgaria	9.4	16.0
Spain	8.7	20.0
EU-27	8.5	20.0
Poland	7.2	15.0
Greece	6.9	18.0
Slovakia	6.7	14.0
Czech Republic	6.1	13.0
Germany	5.8	18.0
Italy	5.2	17.0
Hungary	4.3	13.0
Cyprus	2.9	13.0
Netherlands	2.4	14.0
Belgium	2.2	13.0
United Kingdom	1.3	15.0
Luxembourg	0.9	11.0
Malta	0.0	10.0

environmental impacts should be considered as well to ensure the comprehensiveness of these assessments (e.g. [9,10]). In many cases, scenario assessments can be used to estimate and compare the possible outcomes of the use of different energy sources in order to choose the most sustainable solution (see e.g. [11,12]).

In this paper, we assessed the environmental impacts and risks of renewable energy production in Finland both at a unit process level and at the 2020 target levels. First, we reviewed recent studies on environmental risks and impacts of renewable energy scenarios in European countries. As such comprehensive studies are not currently available (see Section 2. Literature review on renewable energy scenarios in Europe) we applied an approach based on qualitative expert judgement. The recent quantitative literature review by Sokka et al. [8] was used as a starting point for this study. A systematic framework was applied to gather expert knowledge on the impacts and risks of renewable energy production and use in Finland. Finally, we detected hot spots of Finnish renewable energy targets i.e. which renewable energy sources are the most likely to have the most significant environmental impacts at the 2020 target level. This is the first extensive study estimating a relative significance of environmental impacts of the national targets set for all renewable energy sources in Finland.

2. Literature review on renewable energy scenarios in Europe

Renewable energy scenario studies mainly focus on the quantitative assessments of GHG- emissions and climate change, however, some scenarios address environmental issues more comprehensively (e.g. [13–15]). According to most of the scenario studies, renewable energy appears to have smaller GHG-emissions compared to the current energy mixes. Regardless of these reductions, the reduction targets were not always achieved in some of the studies, as in many occasions increased energy demand outweighs the reductions achieved via renewable energy.

Ajanovic [16] estimated that CO_2 emissions of renewable fuels are lower than gasolines, but there are economic constraints involved. In a study by Dimitrijevic and Salihbegovic [17] CO_2 emissions of an energy mix decreased as the proportion of the renewable energy sources was increased. Nevertheless, based on their comprehensive sustainability assessment, a scenario with an addition of 10% of new renewable sources by 2025 would bring the best overall sustainability effects [17]. The benefits of renewable energy with respect to the climate change have also been noticed in assessments done for Spain and Belgium [18]. In Luxemburg, however, only marginal improvements were observed in the climate change mitigation scenario compared to the Business- As-Usual scenario [14]. According to an Austrian study, the utilisation of renewable energy sources does not appear to be a sufficient way to cut down GHG-emissions as they are likely to increase over time, regardless of the energy mix [19]. In Italy, a scenario based on renewable sources had smaller impacts on the reduction of CO_2 emissions than expected [20]. Krewitt et al. [21] defined a worldwide 2 °C scenario (reduction target of global CO_2 emissions 10 Gt/a by 2050 that would limit the temperature increase to 2 °C). In this scenario, by 2050 half of the world's energy would be renewable energy [21].

Renewable energy production systems, especially biomass combustion, cause other emissions besides GHG-emissions e.g. carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), particulate matter (PM) and heavy metals (for a more detailed description on the emissions of biomass combustion see e.g. Brassard et al. [22]). Therefore, it is crucial to consider other emissions besides GHG-emissions. Based on the current scenario studies, the development appears to be positive, as renewables replace heavy polluting energies, such as coal. Based on Maximum Technically Feasible Reduction scenario, the PM2.5 concentration over Europe was reduced by 58% compared to the baseline scenario [23]. At the same time, health impacts (expressed in days of loss of a life expectancy) would decrease by 21% [23]. Mercury emissions are also likely to decrease in the future [24]. This is because coal combustion, which is a major source of mercury emissions, decreases as well.

Most of the renewable energy production systems are far more material intensive in their installation and extraction compared to the current energy sources [25]. Thus, depletion of non-renewable natural resources, besides the climate change, should be evaluated. The transition toward renewable energy sources leads to an increase in the demand of certain metals and rare earths [26]. In a scenario, where GHG-emissions from electricity production would reach the level zero in the UK, the depletion of abiotic resources was estimated to be six and a half times the amount in 2009 [27]. Recycling abiotic resources, such as metals, could reduce this depletion considerably, but depletion of abiotic resources is likely to increase due to the increase in the renewable energy use [27]. Jorge and Hertwich [28] assessed that since an electricity transmission in Europe in 2020 will be more material intensive there will be 10% more metal inputs per kWh compared to the current state. Harmsen et al. [29] studied the influence of copper scarcity on the energy supply, but based on their observation, inverse impacts appear to be equally important as the new energy system leads to a larger energy requirement because of the copper scarcity. The demand of indium may also increase in the future as it is a raw material of solar cells, thus, the increased indium mining may cause adverse environmental impacts [30].

When assessing the impacts of replacing fossil fuels energy with renewables, it is important to also consider land use. Renewable energy, especially bioenergy, can cause both direct and indirect land use changes [31]. Direct land use change involves changes in the land use on the site whereas indirect land use change refers to the changes in the land use that take place elsewhere as a consequence of the bioenergy production [31]. Based on the extensive assessments by Al-mulali et al. [32] it was concluded that renewable energy will increase the land footprint of both developed and developing countries. With

the increasing population and projected consumption levels, converting to 100% renewable energy sources cannot be reached without a considerable conversion of natural land into the biomass production [33]. The challenges connected to an assessment of the land use impacts include methodological difficulties, lack of suitable datasets and problems related to interpretation of many land use related indicators [34].

Based on this literature review, there are no comprehensive assessments on the potential environmental impacts and risks of Finland's renewable energy. As discussed earlier, this kind of assessment would be a more reliable source of information to support decision making compared to one-dimensional assessments. Most of the renewable energy scenarios focused on assessing the GHG-emissions of possible energy mixes, but also other emissions, land use and depletion of minerals were at some cases considered. More comprehensive scenario assessments are also available (see e.g. [13,35,36]), however, none of them can be used to gather information on risks and impacts of the renewable energy production and use in Finland.

3. The expert knowledge to qualitatively assess renewable energy impacts and risks in Finland

The aim of a previous study of our research group was to assess impacts and risks connected to renewable energy sources in Finland [8]. Based on this literature review, it was concluded that different studies (assessing environmental impacts and risks of renewable energies) are not usually comparable to each other. In addition, there are notable data gaps, as all possible environmental impacts or renewable energies are not assessed [8,37]. The aim of this current study is to fill these data gaps. As there are no comprehensive assessments of environmental impacts available in other European countries either (see section Literature review on renewable energy scenarios in Europe) expert panel judgement was considered as a potential option to fill these data gaps.

Expert judgement can be applied to replace non-existing or highly uncertain quantitative parameters [38]. An expert elicitation process can produce high quality, traceable, transparent but explicitly subjective data [38]. In environmental impact assessments, qualitative expert judgment methods are used because they are versatile and easy to apply [39]. Delphi method, for example, which is a structured expert panel communication technique, has been applied to environmental impact assessments and scenarios analyses [40,41]. Experts can be recruited to represent the knowledge on the severity or importance of an environmental impact (e.g. [42,43]), provide expertise of empirical models (e.g. [44]), determine the uncertainty ranges connected to certain parameters (e.g. [38]), to identify a suitable set of environmental indicators or key decision factors (e.g. [45]), and generate potential scenarios (e.g. [46]), for example.

4. Qualitative case-study of renewable energy impacts and risks in Finland

In this study, the impacts and risks of renewable energy production in Finland were assessed qualitatively based on the expert judgement. The aim was to achieve a comprehensive view of all renewable energy production chains with respect to all relevant environmental impact categories. This way all environmental impacts of different renewable energy production systems can be compared to have an overall picture of the environmental consequences of renewable energy production in Finland. The analysis consisted of an expert panel meeting and two additional adjustment rounds via email (Fig. 1). During this process, the effects and risks of the renewable production chains per functional unit (at the unit process level) and with respect to the target levels (at the target use level of The Finnish National Renewable Energy Action Plan) were assessed.

Renewable energy production alternatives were defined as "forest biomass based energy", "agricultural fuels and biogas", and "other technologies", i.e. heat pumps, hydro and wind power and recycled fuels. In Finland, forest energy consists of significant amounts of wood-based fuels, which are utilised for CHP production and heat production. Forest residues are the most common forest energy fraction in this case. Also residential wood combustion is commonly used.

Furthermore, wood is used to produce FT diesel and energy pellets. A considerable part of wood- based energy is derived from by-products of the forest industry, i.e. black liquor, bark and sawdust, however, these industrial by-products were not considered in this study. Agricultural fuels include rape methyl ester (RME) and rape diesel, wheat ethanol and biogas.

The impact categories included in the assessment were:

- Climate change
- Ozone depletion
- Acidification
- Tropospheric ozone formation
- Particulate matter formation: impacts on public health and short-term climate effects
- Eutrophication
- Toxicity
- Impacts on biodiversity
- Soil depletion and soil quality, including organic matter, erosion, nutrient balance, salinization and compaction
- Water use / water footprint
- Land use (land area as a resource)
- Abiotic resource depletion (metals, minerals, fossil fuels)
- Radiation
- Plant pests and diseases

In addition to the environmental impacts, also the following other impacts were considered as they may have an effect on the acceptability of renewable energy sources:

- Noise
- Odour
- Shading and shadow flicker
- Aesthetic impacts and impacts on scenery
- Health impacts (including occupational health)
- Impacts on recreational uses

The experts were selected according to their expertise with the given energy production chains and the associated environmental or health impacts. Altogether 20 Finnish experts, whose studies were used in the review by Sokka et al [8], and /or who attended the assessments during the project (see more details on the project from Leskinen et al. [37]). In the expert panel meeting, the experts were divided into three groups by themes "forest biomass based energy"; 6 experts, "agricultural fuels, biogas"; 7 experts and "other technologies", i.e. heat pumps, hydro and wind power and recycled fuels; 7 experts. The division of the experts into the groups was done based on their expertise.

Prior to the expert panel meeting, a preliminary qualitative unit process impact assessment table was generated by the research group based on the results of the literature review and the expert interviews (see more details [37,8]). At the beginning of the panel meeting, the results of the literature review were introduced (see Supplementary material 1. for the results of a literature review), following by the presentation of the preliminary qualitative classification of the unit process impact assessment table. The overall task of the expert panel was first to modify and validate the unit process table for each production process and impact category. After that, same kind of impact assessment table was created to assess the impacts of 2020 renewable targets. The experts were advised to use the following qualitative scale: not significant - to some extent significant –

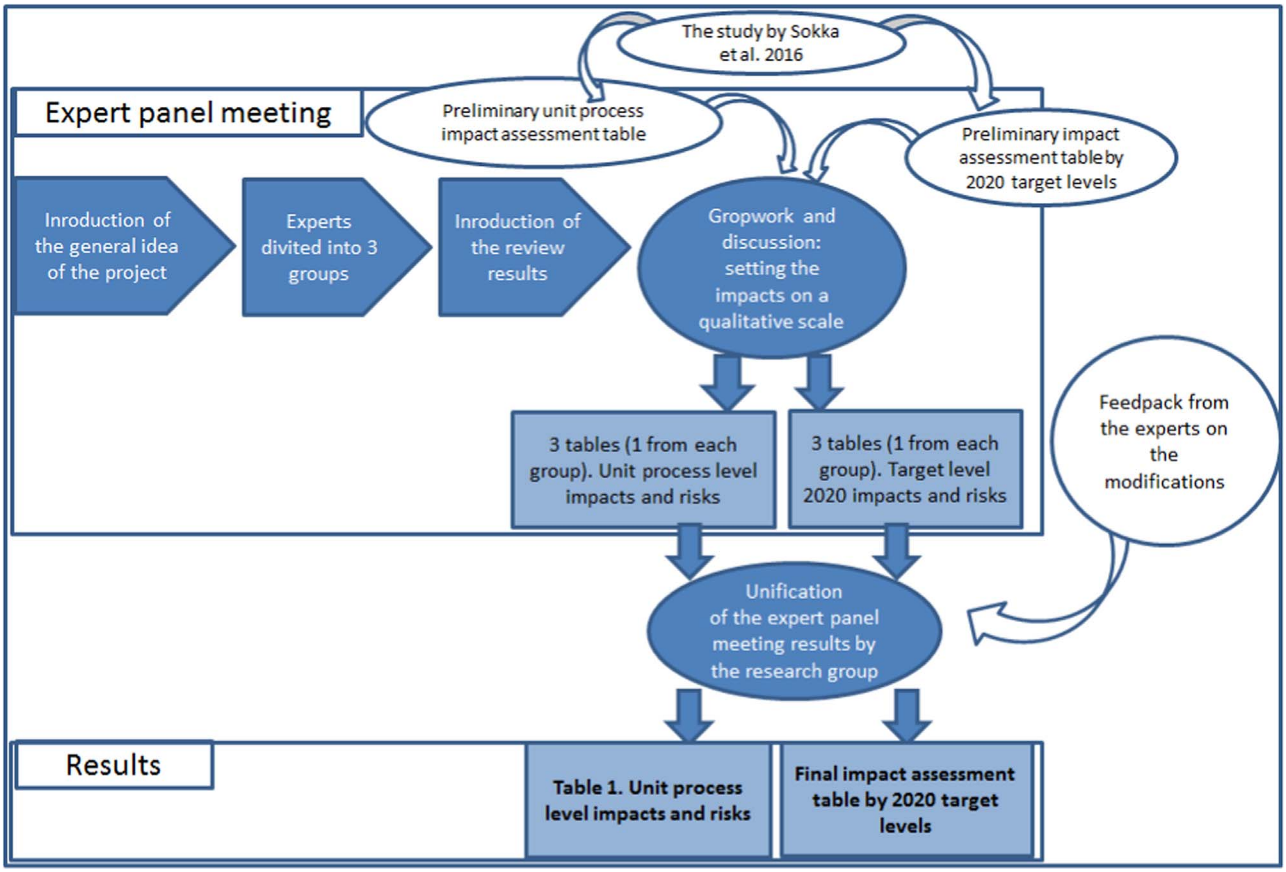

Fig. 1. A flowchart of the expert panel meeting and the process of generating the impact assess- ment of renewable energy production.

significant – or –very significant– in their judgements. This qualitative scale with the four steps was considered a convenient option as it is comprehensible to use and interpretation of the scale is coherent. The experts evaluated the impacts using the following rules: if the impacts are evident or to be expected, but they are not considered to be large "to some extent significant" should be used. In a case of important local, regional or global impacts the effect should be considered “significant”. Major effects on the public health or the environment were denoted by “very significant”. If the anticipated effects or emissions are diminishingly small, or the effects do not exist, the category was “not significant”.

The members of the expert panel first discussed the impacts and risks of each energy production system in general and then modified the unit process table according to the verbal scale. The expert panel determined the severity of environmental impacts and risks considering the impacts of all life cycle stages, but the contribution of the different stages to the verbal evaluation were not identified, only the overall impact. Similarly, their task was to estimate the overall environmental and health impacts and possible risks caused by the energy production according to the 2020 targets.

Since the expert groups had used slightly different scales when estimating the impacts, the research group made some minor modifications to the impact assessment tables after the panel meeting. For instance, according to the discussions within the groups, one group considered a minor impact of renewable energy source as “not significant”, whereas another group estimated a similar impact to be “to some extent significant”. In cases like this, an impact was considered “to some extent significant” in the impact assessment table. Also, if the groups disagreed, i.e. one group member suggested that the impact was “significant” and other group considered the same impact “very significant”, both of these judgements were included to the impact assessment table. After the modifications, the experts received the finalised impact assessment tables via email. First, the experts received the partial impact assessment table concerning their own expert group’s results. Then they received the total impact assessment tables (including all renewable energy sources and their anticipated impacts at the unit process level and the level by 2020). The experts were given an opportunity to modify the impact assessment tables. They were able to comment on the changes made by the research group and the other experts group. They also approved the final versions of the impact assessment tables.

5. Results

5.1. Impacts and risks of renewable energy in Finland based on the expert panel assessment

The experts from various Finnish organisations evaluated the environmental impacts and risks connected to renewable energy at the unit process level (see Supplementary material 2 for more details). Also the impacts and risks at the target level in Finland by 2020 were evaluated. The following results concerning impacts and risks of renewable energy are based on the judgements of the expert panel (for more details on the results, see also Leskinen et al. [37]).

5.1.1. Forest energy

At the unit process level, experts estimated climate change to be a “significant” impact category in all forest energy production options. There was a lot of discussion among experts about the climate impacts of forest energy production. The impact category was considered to be “significant” also for the reason that there are still many open questions concerning the determination and calculation of these impacts, as well as the system boundaries of the calculations.

The experts agreed that fine particles released especially from a residential wood combustion are a risk to the public health as they cause serious health problems. Therefore, this impact category was classified as “Very significant”. Due to lower combustion temperatures and poor cleaning techniques, fine particulate emissions of the district heating plants were estimated as a “significant” risk to the public health. Instead, particulate matter emissions from the use of other forest energy types were evaluated as “some extent significant”. With regards to a small-scale wood combustion, the soot generated during the combustion may enhance global warming. Because of this effect, also the short-term climate effects of particulate matter were “significant” according to the experts.

Deadwood is an important habitat for many forest species. Therefore, biodiversity effects were estimated as “significant”, since the harvesting material, such as stumps, decreases the amount of decaying wood. In addition, the energy wood harvesting increases somewhat the intensity of forest management, which has an additional impact on the biodiversity. The experts agreed, that the long term impacts of forest energy biomass harvesting are not adequately understood, thus, more research concerning this topic was considered important.

Acidification, tropospheric ozone formation (during biomass burning), eutrophication, soil's productive capacity (including impacts on the amount of organic matter, erosion, nutrient balance, and compaction), plant pests and diseases, as well as aesthetic impacts and impacts on the scenery were considered “some extent significant”. The occupational health effects of dust and risks of occupational accidents, as well as odour due to the wood combustion were also evaluated to be “some extent significant”. As the district heating plants, CHP power plants, and pellet and pyrolysis oil production may cause noise pollution, these effects were considered “some extent significant”. CHP production adds water consumption to some extent, thus, water use was considered to be “some extent significant”. All energy production forms that require infrastructure were considered “some extent significant” in terms of the abiotic resource depletion.

5.1.2. Hydropower

The impacts of hydropower depend on the hydropower plant type – dam reservoir or run-of-river power plant. Reservoir dams cover vast areas under water and may cause considerable methane emissions when organic matter is decomposed under water. The climate change impacts of hydropower were considered to be ”some extent significant” or “significant”. Eutrophication, biodiversity, erosion and water use impact categories were also marked as ”some extent significant” or “significant” by the expert panel. Land use was considered “significant” impact category. There is also some local noise pollution, aesthetic impacts and scenery depletion and negative impacts on the recreational uses, thus they were considered to be ”some extent significant”. Also abiotic resource depletion was identified as ” some extent significant”.

5.1.3. Wind power

Wind power was recognized to cause mainly ”some extent significant” local environmental impacts at the unit process level, such as aesthetic impacts and impacts on scenery, land use and biodiversity depletion. Additionally, wind turbines cause shading and shadow flicker, thus they were considered “significant”. The depletion of abiotic resources is ”some extent significant”. GHG-emissions are mainly caused by material acquisition and decommissioning phases. Experts estimated climate impacts to be ”some extent significant”.

5.1.4. Solar power

Environmental impacts of solar collectors and solar panels are mainly caused during the manufacturing phase – especially the production and procurement of the raw materials. Climate change, acidification, fine particulate emissions, tropospheric ozone, impacts on biodiversity and water use were considered “not significant” or ”some extent significant”. Toxicity was estimated to be ”some extent significant” impact category. Rare minerals and metals are used in the manufacturing, which is why the experts estimated abiotic resource depletion as “significant”. Solar collectors and panels are often placed in visible places, thus, the aesthetic impacts and impacts on the scenery were considered ”some extent significant”.

5.1.5. Geothermal energy

Main environmental impacts related to ground-source and air-source heat pumps are dependent on the electricity used to produce and operate the pumps. The expert panel estimated the impacts as ”some extent significant” or “significant”. In addition, due to use of many rare metals, the abiotic resource depletion was noted ”some extent significant”. There are local impacts due to structural solutions of the pumps such as noise, aesthetic impacts and impacts on the scenery. These impacts were considered ”some extent significant”.

5.1.6. Agricultural fuels, Biogas

Most of the environmental impacts of energy crops are associated with the cultivation phase, in which the use of fertilizers and working machines cause emissions. At the unit process level, eutrophication caused by the production of rapeseed biodiesel, barley and wheat ethanol was evaluated to be “very significant” by the expert panel. In addition, climate change and land use was estimated as “significant” impact category. In the case of rapeseed cultivation, also the impact category ‘plant pests and diseases’ was noted as “significant” since considerable increase in the amount of rapeseed increases the likelihood of pests of cruciferous plants. For barley and wheat ethanol this impact category was estimated as “some extent significant”.

The use of energy crops was evaluated as “some extent significant” for the following impact categories: acidification, particulate matter formation, tropospheric ozone formation, toxicity, impacts on biodiversity and soil depletion. Also, with regards to non-renewable resources, especially the use of fossil fuels in the cultivation and processing phase - as well as the use of fertilizers, the impacts were considered to be “some extent significant”. Occupational health impacts were also considered to be ”some extent significant”, as there is a risk of occupational accidents in the crushing phase. Also, dust formed in the material handling and storage phase can cause health effects. All other impact categories were estimated to be “not significant”.

Eutrophication was considered to be the only impact category of biogas utilisation that was “significant” or ”some extent significant” at the unit process level. It was agreed, that the effect depends on the raw material used in the system. For instance, the cultivation of grass may cause eutrophication whereas the utilisation of waste plants or manure does not. Climate impact of biogas was estimated to be “not significant” or “some extent significant”. The climate impacts are caused by the methane emissions or a leakage from the production and refinement phase and from the storage of digestate. The use of cultivated plants as raw material also causes GHG-emissions. Biogas usage phase causes ”some extent significant” acidification impact, tropospheric ozone formation and emissions of fine particulates. Impacts on the factors affecting the soil nutrient balance were estimated to be “not significant”. Biogas plants may cause local odour nuisance, yet the digestion reduces the smell of manure, thus, it was considered “not significant”.

5.2. Risks and impacts at 2020 target levels – all renewable energy sources

At the target levels of 2020, the impacts of forest biomass were considered greater than the impacts of the other renewable energy sources. The reason for this is that the production volumes of forest energy are the largest. When environmental effects were related to the 2020 renewable energy targets, the experts evaluated fine particles released (especially from residential wood combustion) as a risk to public health, thus this impact was considered to be “very significant”.

"Significant" impact categories were considered to be the climate impacts of forest energy (district heating plants, CHP power plants and residential wood combustion), short-term climate effects of particulate matter and biodiversity impacts caused by all forest biomass utilising energy production forms.

For other renewable energy sources, "significant" impacts were recognized only for agricultural fuels, namely eutrophication. The eutrophication impact results mainly from the use of fertilizers. Still, in the case of agricultural fuels and biogas, the produced amounts by 2020 are anticipated to be so small that the overall impacts remain low. The Finnish target level for hydropower production in 2020 may require building a new hydropower capacity. Environmental impacts related to the existing hydropower production are fairly small, but the climate change and the biodiversity impacts related to new hydropower dams can be considerable. Therefore, the biodiversity impacts of hydropower were considered "significant".

According to the expert panel, the rest of the environmental impacts of the assessed renewable energy sources (when the 2020 target levels were taken into account) were not considerable (i.e. they were not considered "significant" or "very significant"). Toxicity, biodiversity, plant pests and diseases, occupational health, soil depletion and soil quality, including organic matter, erosion, nutrient balance and compaction impacts of agricultural fuels were estimated to be "some extent significant". However, many of these impacts were considered to be already under control as there are legislations that regulate e.g. the use of plant protection chemicals. Climate impact was valued as "not significant" for all the other agricultural fuels, but for rape biodiesel it was estimated to be even "some extent significant ", because rape yield is low and rape diesel has the biggest share of renewable transportation fuels used in Finland.

The use of geothermal energy and wind power was estimated to have some impacts. Heat pumps cause emissions mainly in the manufacturing phase. Accordingly, climate change, acidification, tropospheric ozone, fine particles and abiotic resource depletion were notified as "not significant" or "some extent significant". For air source heat pumps, also aesthetic impacts and impacts on the scenery were considered to be "some extent significant". The use of wind power is likely to increase in Finland by 2020 (Table 2), yet abiotic resource depletion, noise at some cases, aesthetic impacts, impacts on scenery, and shading and shadow flicker were identified as "not significant" or "some extent significant". Impacts on the biodiversity were considered "not significant", unlike at the unit process level.

Biogas was estimated to have "not significant" or "some extent significant" impacts on climate change and land use, and "some extent significant" impacts on biodiversity and on health impacts and occupational health. The impacts depend on the raw material. The experts pointed out, that biogas production may also have positive impacts, e.g. the digestate can be used as a fertilizer that improves the quality of soil. The impacts of least significance at the 2020 target levels were identified for solar power – all the impact categories were considered "not significant".

Table 2
Finnish targets for the use of renewable energy by 2020.

Renewable energy source	2010	Target 2020
Forest residues in CHP and heat production	14.00 TWh	25.00 TWh
Pellets	0.70 TWh	2.00 TWh
Residential wood combustion	12.00 TWh	12.00 TWh
Wind power	0.30 TWh	6.00 TWh
Hydropower	12.70 TWh	14.00 TWh
Biogas	0.50 TWh	0.70 TWh
Liquid biofuels in transportation		7.00 TWh
Agricultural biomass	0.60 TWh	Use is increased
Heat pumps	3.10 TWh	8.00 TWh
Waste fuels	1.70 TWh	2.00 TWh
Other renewables, including solar power	0.40 TWh	0.40 TWh

6. Discussion

The aim of this study was to detect the impacts and risks connected to renewable energy in Finland. The impacts and risks were evaluated both at the unit process level and by the target levels of 2020. At the moment, it is not possible to quantitatively assess these impacts, as the currently available studies and datasets are not comparable, include substantial uncertainties and data gaps and are not applicable for the Finnish circumstances [8,37]. Therefore, the approach applied in this study relies on qualitative expert knowledge. A panel consisting of renewable energy production experts assessed the severity of impacts and risks connected to renewable energy production in Finland. The expert panel valuated the impacts by using a qualitative scale in their judgements. We first analyse the results of these assessments and then consider the benefits and drawbacks of using such approaches.

6.1. Analysis of the expert panel assessment of environmental impacts of renewable energy in Finland

According to the expert panel, environmental impacts of most of the renewable energy sources in Finland are rather small at the unit process level as well as at the 2020 target level (for more details, see Supplementary material 2). However, the impacts cannot be ignored as the role of renewable energy may increase over the 2020 target levels in the future, and some impacts that appear small today may be of greater importance in the future [8,47,48]. Therefore, it is important to study environmental impacts of renewable energy sources also with quantitative scenario assessments. These take into account different shares and usage levels of renewable energy sources in order to improve the understanding of the associated impacts and risk and the long-term impacts of each renewable energy production chain (see also [8]). As the review by Sokka et al. [8] points out, a thorough life cycle assessment with a unified framework is needed in order to comprehensively understand the overall environmental impacts of the different renewable energy sources. Altogether, energy systems should be evaluated as a whole, not only as individual energy forms. Since generating this type of unified framework is demanding and time consuming, applying a qualitative framework based on expert knowledge, as described in this study, is one option to attain information on the environmental impacts of renewable energy. The results of this qualitative expert analysis are in line with our previous quantitative study [8]. Therefore, we suggest that the qualitative expert panel can provide moderately reliable information. Furthermore, a qualitative framework provides information on sustainability "hotspots", i.e. which renewable energy forms are the most significant ones that should be further studied. Nevertheless, defining an optimal energy mix should take into a consideration the technical limitations. For instance, despite the good performance with respect to environmental impacts, solar energy does not currently appear a suitable candidate as a main source of energy production in Finland. Moreover, in addition to environmental impacts and other sustainability targets, an optimal energy mix should take into a consideration energy security.

Forest energy was at the target levels by 2020 in Finland the main contributor of the environmental impacts. This is because wood is anticipated to be one of the most important renewable energy sources in the future (Table 2). However, the experts had varying perceptions on the actual climate change impact of forest energy. They agreed that the calculation methods of the forest energy climate impacts should be further developed. According to the literature reviews by Sokka et al. [8] and Koponen et al. [5] climate impacts of wood based energy have a wide range because of technical assumptions of the climate impact calculations. Also, political discussions on the forest energy and the climate change appear relevant, as the time frame used in the calculations depend on the climate policies [5].

Also, fuel based on palm oil was considered to be a significant contributor to the environmental impacts both at the unit process level

and by 2020 target level (see supplementary material 2 for more details). There are several environmental and socio-economic sustainability impacts of palm oil production, thus attaining renewable energy targets via palm oil use has been criticized [49,50]. However, a recent study advocates that a further cultivation of peatlands and forests because of palm oil production may be avoided, at least in Indonesia [51].

Eutrophication caused by some agricultural energy sources were also highlighted by the expert panel because agriculture is causing the majority of eutrophication of Baltic Sea. In Finland, 60% of phosphorus and 52% of nitrogen load caused by human activity is from agriculture [52]. Nitrogen and phosphorus leaching is mainly caused by the use of fertilizers. However, there are some practices that could decrease the risk of leaching, e.g. fertilizer placement. Environmental aid scheme has the aim to control eutrophication caused by cultivation. It is not obligatory, but majority of farms want to get environmental aid and thus follow the support conditions.

Fine particle emissions of the residential wood combustion and their impacts on the human health have been under discussion in Finland. Therefore, also the expert panel estimated this impact category to be considered, especially in the future if the residential wood combustion becomes more popular. Air pollution is estimated to be the reason behind up to 1600 premature deaths in Finland every year [53]. Nevertheless, it is not possible to describe, what is the role of the residential wood combustion in this picture, as air pollution is also caused by e.g. other energy production systems, traffic exhaust gases, street dust, peat production and industry [53]. Technical improvements in the combustion systems play a key role in the emission reduction [54], thus, with advanced combustion systems, emissions could be controlled. The particulate matter emissions were also considered a significant contributor to the short-term climate change impacts, and therefore, the emissions reduction alleviates also climate change mitigation.

Based on qualitative expert assessments several renewable energy forms (i.e. district heating plants, CHP power plants, residential wood combustion, wood pellets, hydropower and palm oil diesel) have significant impacts on the biodiversity. However, renewable energy scenarios seldom include an assessment of biodiversity impacts. The problems connected to assessment of biodiversity impacts are connected to e.g. data availability and methodological drawbacks [10]. Furthermore, the biodiversity impacts are highly case-specific i.e. the local circumstances should be taken into consideration. Based on this study, the anticipated biodiversity impact in Finland is connected to wood based energy. Therefore, the development of biodiversity impact assessment methods and tools should be developed to assess biodiversity impacts of forestry.

During the expert panel meeting it was criticized that only negative effects were taken into account as some renewable energy forms could also cause positive effects. Experts' opinion was that also positive effects should be taken into account when making comparisons between different energy forms as sometimes positive effects could be greater than negative effects. For instance, biogas production may have several positive impacts as weeds and pathogens are being killed during the process [37].

6.2. Expert knowledge in renewable energy impact assessment scenarios

The aim of this study was to assess environmental impacts and risks of renewable energy production in Finland. Currently, there are no quantitative datasets available for such assessment [8,37]. In this particular case study, using expert knowledge appeared to be the only option to gather information on the impacts of renewable energy sources in Finland. Using expert knowledge to assess impacts of renewable energy has several advantages. Firstly, expert knowledge is an efficient and convenient way to attain information on many possible, yet not well-understood, impacts and risks. Uncertainties connected to qualitative data can be addressed e.g. by determining impacts by using a numerical range instead of one fixed value. Also, it should be noted that uncertainty is high in quantitative scenario studies as well (e.g. [4,5,38]). Another benefit of using an expert panel is that the experts are usually familiar with the local circumstances. In other words, using a quantitative model originally developed to be used at some completely different region may lead into biased results whereas an expert is able to use his/her expertise to assess the local impacts in a more reliable manner (see e.g. a case study by Leskinen et al. [44]). Also, experts may have some unpublished data and tacit knowledge which they can build their judgements on.

The expert groups applied a qualitative assessment scale to assess environmental impacts of renewable energy. The selected assessment scale was verbal and contained only four different steps. We could have used a quantitative scale, e.g. according to the tools of Multi Criteria Analysis (MCA). For example, Keeney and Raiffa [55] have proposed the use of an interval scale, and Saaty [56] a ratio scale. This case study was considered to be complicated due to the large number of impact categories and production technologies, and also major unknown parameters were involved. Therefore, our hypothesis was that it was easier to obtain responses by using the assessment scale such as used in this study. This was also verified during the process due to an experts' relatively positive reaction and a coherent and logical outcome of the assessment. Also, another benefit of using a full MCA approach could be, that the comparisons of e.g. different renewable energy sources, technologies or scenarios are possible [13,35].

Using an expert panel to assess environmental impacts of renewable energy production presents also some limitations and sources of uncertainties. For instance, in order to actually compare the impacts of different renewable energy forms, the experts should be explicitly specialized on a wide range of renewable energy production forms. Nevertheless, the expertise is usually limited to one or some energy forms or environmental impact categories. This results in challenges in comparison of different renewable energy sources. In this study, the problem was to some extent managed by using expert panel groups focused on their own field of expertise. The research group with a wide expertise on renewable energy then adjusted the impacts assessment table so that the judgements of different expert groups were in line. Another problem in this case study is, that the expert panel groups did not explicitly consider the impacts with respect to production processes allocated to other groups (forest energy versus agricultural energy, for instance). However, the experts of each group were given an opportunity to modify and comment the judgements by the other group of experts. In other words, if an expert of "forest biomass energy group" disagreed with the judgements made by "agricultural fuels, biogas group", (s)he was able to comment on that.

7. Conclusions

Because of the problems related to the reliability and scarcity of suitable datasets, all possible environmental impacts of renewable energy in Finland are not yet quantitatively assessed. In order to achieve a comprehensive overview of the possible environmental impacts and risks, qualitative expert knowledge was applied instead. Based on the expert panels' knowledge, the environmental impacts of most of the renewable energy sources in Finland are rather small both at the unit process level as well as at the 2020 target levels. The environmental impact hot spots, i.e. areas of the most concern are connected to particulate matter emissions originating from the residential wood combustion (and their impacts on the human health), climate change impacts of forest based energy systems, biodiversity and land use impacts of several renewable energy sources and eutrophication caused by agricultural energy sources. The experts agreed that, there are currently no reliable methods to estimate the biodiversity impacts of renewable energy production and would require

further method development. Climate change impacts of forest based energy sources, on the contrary, are moderately well studied, but the results of these studies are highly variable because of different methodological assumptions behind the calculations. Based on our experiences, a qualitative impact assessment framework as described in this paper can be used to assess environmental impacts of renewable energy production. Also, such approach could be used to assess the environmental impacts of renewable energy production in other countries or even at the EU level as long as comprehensive, quantitative assessments are not feasibly implemented.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.rser.2017.05.146.

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